IEEE/NASPI Oscillation Source Location Contest

October 7, 2021

Jim Follum, PNNL
Slava Maslennikov, ISO-NE
Evangelos Farantatos, EPRI
Panel Overview

- Oscillation analysis is one of the highest-value synchrophasor applications
- IEEE teamed with NASPI to host a contest for oscillation source location methods based on synthetic PMU data
- Top three performers will present their approaches:
  - Third place:
    - Team FIUBA, University of Buenos Aires
    - Pablo Gill Estevez, Pablo Marchi, Cecilia Galarza
  - First place (tie):
    - Team Woodpecker, General Electric
    - Honggang Wang, Shaopeng Liu, Gang Zheng
  - First place (tie):
    - Team RPI, Rensselaer Polytechnic Institute
    - Denis Osipov, Stavros Konstantinopoulos, Joe H. Chow
Problem Overview

• Forced oscillations occur when a piece of equipment injects a periodic disturbance into the power system
  ▪ Example: January 11, 2019 forced oscillation event in the US Eastern Interconnection
  ▪ Combined cycle power plant in Florida experienced a faulty input to a control system
  ▪ Oscillations persisted across interconnection for approximately 18 minutes
  ▪ Plant operator removed unit from service in response to control room alarms

Figure credit:
[Source: AEP]
Problem Overview

• Forced oscillations occur when a piece of equipment injects a periodic disturbance into the power system
  ▪ Example: January 11, 2019 forced oscillation event in the US Eastern Interconnection
  ▪ Combined cycle power plant in Florida experienced a faulty input to a control system
  ▪ Oscillations persisted across interconnection for approximately 18 minutes
  ▪ Plant operator removed unit from service in response to control room alarms

• Response times can be reduced with oscillation source location tools
  ▪ Once responsible equipment is identified, corrective action can be taken

• Source location is a challenging problem
  ▪ Amplitude not always largest at the source
  ▪ Sources are varied

• Many solutions have been proposed
Contest Overview

• Objectives
  ▪ Help academia and vendors further develop and improve source localization tools
  ▪ Help utilities identify and evaluate tools for practical use

• Joint effort by IEEE’s Oscillation Source Location Task Force (OSL-TF) and NASPI

• Participation: 60 sign-ups, 21 submissions

• Special thanks
  ▪ Contest coordinator: Frankie Zhang (ISO New England)
  ▪ Web support: Kai Sun (UTK), Teresa Carlon (PNNL)
  ▪ WECC-240 bus base case: Jin Tan and the rest of the NREL team
  ▪ TSAT simulation technical and license support: Powertech Labs
Contest Committee

Ning Zhou  
(Binghamton Uni.)

Jim Follum  
(PNNL)

Athula Rajapakse  
(Uni. of Manitoba)

Bin Wang  
(NREL)

Slava Maslennikov  
(ISO-NE)

Mani Venkatasubramanian  
(WSU)

Evangelos Farantatos  
(EPRI)

Jeff Bloemink  
(Powertech Labs)
Philosophy for Creation of Simulated Cases

• Realism
  ▪ Mix of local and interarea natural oscillations
  ▪ Realistic modeling of all system components including “colored noise”
  ▪ Synthetic PMU measurements by time-domain simulation
    ➢ Partial system observability by PMUs
    ➢ P/M PMU class mix; missed samples

• Properties of FO:
  ▪ Source located at Generator (Governor & Exciter), Load, HVDC
  ▪ Variable magnitude and frequency
  ▪ Obfuscated onset
  ▪ Multiple sources; resonance with natural modes
  ▪ Harmonics
  ▪ Strong interaction with controls

• Avoid bias for any known source locating method
Case Creation Data Flow Process

Input data preparation → Run TSAT → Convert results into “Test cases library” format

PMU Emulator to mimic P/M PMU class → Add “missed” samples → Synthetic PMU data set

Scenario design:
• High level description
• Technical implementation

Final verification and benchmarking
Power System

• NREL’s new 240-bus WECC model
  ▪ [https://www.nrel.gov/grid/test-case-repository.html](https://www.nrel.gov/grid/test-case-repository.html)
  ▪ Four areas: North, South, California, Mexico
  ▪ 109 synchronous generators
### Features of 13 Test Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Key Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Easy case to “warm up”</td>
</tr>
<tr>
<td>2</td>
<td>Observable source; resonance with local mode</td>
</tr>
<tr>
<td>3</td>
<td>Non-observable source in the exciter; resonance with system-wide inter-area mode</td>
</tr>
<tr>
<td>4</td>
<td>Non-observable source in the governor; resonance with system-wide inter-area mode</td>
</tr>
<tr>
<td>5</td>
<td>Variable frequency of FO</td>
</tr>
<tr>
<td>6</td>
<td>Non-observable source; resonance with local mode</td>
</tr>
<tr>
<td>7</td>
<td>Source in the exciter; strong interaction with controls</td>
</tr>
<tr>
<td>8</td>
<td>Observable source; resonance with regional inter-area mode</td>
</tr>
<tr>
<td>9</td>
<td>2 sources: (1) FO source in the governor, (2) wrong tuning of PSS in another generator</td>
</tr>
<tr>
<td>10</td>
<td>2 sources of FO resonating with local and inter-area modes</td>
</tr>
<tr>
<td>11</td>
<td>Source of FO in Load</td>
</tr>
<tr>
<td>12</td>
<td>Rectangular shape of forced signal creating wide spectra of oscillations</td>
</tr>
<tr>
<td>13</td>
<td>Source of FO in HVDC</td>
</tr>
</tbody>
</table>

- Largest MW magnitude oscillation not in the source
- System disturbance obfuscating the FO onset
• To investigate sensitivity of participants’ OSL algorithms to PMU filtering
  ▪ No scoring for 14th test case
• FO with single source and 3 frequencies
• Scenarios
  ▪ Mix P/M Class PMUs
  ▪ All P Class PMUs
  ▪ All M Class PMUs
• EPRI’s PMU Emulator
  ▪ Models PMU signal processing
  ▪ Input: Simulation output of electromechanical or EMT simulators (e.g., TSAT or PSCAD)
Data Provided to Participants

1. Model with system conditions similar to those used in simulations (PSS/E format)
   - Important for use of Model-based and Machine Learning methods

2. For each of 13 cases: synthetic PMU measurements (TSAT simulation output) (txt files)
   a) Bus voltage magnitude
   b) Bus voltage angle
   c) Line current magnitude
   d) Line current angle

Participants were required to:
- Identify the source of oscillation (Area, Bus, Equipment type, Controller type)
- Submit solution by using a provided template document
OSL Methods Used by 21 Contestants

<table>
<thead>
<tr>
<th>Group #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Energy-based methods</strong> (DEF, Transient energy, Dissipating potential, Energy supply on port)</td>
</tr>
<tr>
<td>2</td>
<td><strong>Oscillation shape and magnitude</strong> (Phase relation at the onset of oscillation, Magnitude of oscillation, Mode shape)</td>
</tr>
<tr>
<td>3</td>
<td><strong>Machine Learning and Model-based analytics</strong> (ML pattern recognition, Spectral estimate, Ensemble of analytical estimates, Graph neural network, Advanced statistical learning)</td>
</tr>
<tr>
<td>4</td>
<td><strong>Cross Power Spectra Density</strong> (energy-based approach is the core)</td>
</tr>
</tbody>
</table>
## Summary of OSL Contest Results

### Winners; close to 100% performance

| Team | 1/2 | 1/2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|------|-----|-----|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Score | 110 | 110 | 99 | 82 | 77 | 76 | 71 | 68 | 62 | 57 | 55 | 44 | 47 | 46 | 45 | 42 | 38 | 37 | 25 | 18 | 17 |
| Used Method | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

**Methods**

1: Energy-based
2: Oscillation shape and magnitude
3: Machine Learning and Model-based analytic
4: Cross Power Spectra Density
# Conclusions

## Methods

1. **Energy-based**
2. Oscillation shape and magnitude
3. Machine Learning and Model-based analytic
4. Cross Power Spectra Density

## Table of Scores and Used Methods

<table>
<thead>
<tr>
<th>Team</th>
<th>1/2</th>
<th>1/2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>110</td>
<td>110</td>
<td>99</td>
<td>82</td>
<td>77</td>
<td>76</td>
<td>71</td>
<td>68</td>
<td>62</td>
<td>57</td>
<td>55</td>
<td>44</td>
<td>47</td>
<td>46</td>
<td>45</td>
<td>42</td>
<td>38</td>
<td>37</td>
<td>25</td>
<td>18</td>
<td>17</td>
</tr>
</tbody>
</table>

- **Energy-based methods** are most efficient
- **ML and Model-based methods** are less efficient
- Details of implementation could be critical
- Complementary use of ML and Model-based method seems to be beneficial
PMU Class Sensitivity Test Results, Case 14

• PMU filtering for low frequency FO (<1Hz) is not expected to affect the results much
• Results of 11 participants (from 13 submitted) are NOT sensitive to PMU class
• Results of 2 participants differ depending on PMU class

<table>
<thead>
<tr>
<th>Method</th>
<th>All Correct</th>
<th>Some Correct</th>
<th>All Wrong</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Energy-based</td>
<td>5</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2: Oscillation shape and magnitude</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3: Machine Learning and Model-based analytic</td>
<td>1</td>
<td>4</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4: Cross Power Spectra Density</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A Lasting Resource

- Contest website: [http://web.eecs.utk.edu/~kaisun/Oscillation/2021Contest/](http://web.eecs.utk.edu/~kaisun/Oscillation/2021Contest/)
- NREL’s WECC 240-bus model: [https://www.nrel.gov/grid/test-case-repository.html](https://www.nrel.gov/grid/test-case-repository.html)
- Test case library: [http://web.eecs.utk.edu/~kaisun/Oscillation/](http://web.eecs.utk.edu/~kaisun/Oscillation/)
  - 2016 simulation cases based on WECC 179-bus model
  - Field-measured cases
  - IEEE-NASPI contest cases and data set-ups for simulation: [http://web.eecs.utk.edu/~kaisun/Oscillation/contestcases.html](http://web.eecs.utk.edu/~kaisun/Oscillation/contestcases.html)

Please consider using the test case library when testing and publishing
Thank you